The important role of the Gulf region in abating global GHG-emissions and securing sourcing of metallics

Rutger Gyllenram [1], Niloofar Arzpeyma [2], Wenjing Wei [3], Seyed Mohamad Seyedali [4],

rutger.gyllenram@kobolde.com.

Abstract

The pressure on the international steel industry to lower its emissions, especially of CO_2 is profound. Major steel companies perform long term research on new processes but it will take many years before they are ready to be put in operation. Today some companies plan to close integrated mills and become scrap based possibly resulting in a shortage of scrap. A today well-established way to produce iron from iron ore with lower CO_2 emissions is the DRI-route. Direct reduced iron, DRI, is a commercial product made from iron ore that has been reduced in solid state, predominantly by natural gas. Natural gas consists mainly of CH_4 in its natural form, and CO and $2H_2$ when reformed, resulting in a lower CO_2 emission when used as a reduction or energy gas compared to solid carbon. DRI can be used in steelmaking in the same way as steel scrap in the electric arc furnace, or as part of the burden in a blast furnace to reduce coke consumption. The driving forces for an increased DRI production are abating CO_2 emission for reduction and avoidance of reinvestment in coke plants. This paper investigates the consequences of a drastically increased DRI demand and the opportunities this would offer the Gulf region, taking into account limitations in the supply of iron ore and natural gas.

Keywords: GHG, Coke plant, DRI, Blast furnace, Electric furnace, Slag

1- Introduction

1-1- The role of DRI

The pressure on the international steel industry to lower its emissions of CO_2 is profound. Of the 40000 million tons (Mton) of CO_2 emitted by human activities each year the steel industry accounts for 7-9%. [1]. Ways to abate CO2 emissions are numerous [2]. Major steel companies perform long term research on new processes such as ArcelorMittal with electrolysis and SSAB and VoestAlpine with hydrogen reduction processes making reduction CO_2-emission free. In the EU-funded ULCOS project ways to reduce the CO_2 have been tested like the Oxygen Blast Furnace and the HISarna smelting reduction process now developed at Tata Steel. A today well-established way to produce iron from iron ore with lower CO_2 emissions is the DRI-route. Direct reduced iron, DRI, is a commercial product made from iron ore that has been reduced in solid state, predominantly by natural gas. Natural gas consists mainly of CH_4 in its natural form, and CO and $2H_2$ when reformed, resulting in a lower CO_2 emission when used as a reduction or energy gas compared to solid carbon. The off-gas from a modern DR-shaft does not contain

1- CEO, Kobolde & Partners AB, Royal institute of technology (KTH), Sweden
2- Researcher, Kobolde & Partners AB, Royal institute of technology (KTH), Sweden
3- Researcher, Kobolde & Partners AB, Royal institute of technology (KTH), Sweden
4- CEO, Kimia, Iran

Nitrogen as blast furnace gas does and CO_2 is therefore easier to capture. [3]. DRI can be used in steelmaking in the same way as steel scrap in the electric arc furnace, or as part of the burden in a blast furnace to reduce the coke consumption [4]. According to Worldsteel [5] [6], of the 1,807 Mton of crude steel produced in 2018, 1,279 Mton was produced by the blast furnace route with oxygen converters and 520 Mton in electric furnaces using scrap and DRI as source. The blast furnace hot metal production was 1,247 Mton and the DRI production 100 Mton including both gas based and coal based DRI. The biggest net scrap importers in the world are Turkey and some countries in Asia and among the biggest net exporters you find EU, NAFTA and Japan. The international scrap trade in 2018 was around 100 Mton to be compared to an international iron ore trade in the range of 1,600 Mton. With an iron ore production of 2,167 Mton (2017) the trade represents 74% of the production. Assuming the external scrap in the BF route is 10% of the steel production the use would be 127 Mton in oxygen converters the need for scrap and scrap substitutes would be in the range up to 700 Mton indicating that the international scrap trade is around 15% of the market.

1-2- Location of DRI production

Iron ore is today transported long distances mostly by seaborne transport and by rail. Natural gas is transported by pipeline or as seaborne Liquefied Natural Gas, LNG. While the cost for sea transport can be in the range of 10 EUR/ton of ore [7] the production cost for turning natural gas into LNG and ship it and handle it at a destination port is in the range of 3 EUR/GJ [8]. Since the use of natural gas in DR-production is around 10 GJ /ton DRI locating DR production close to the natural gas sources is motivated. Furthermore, storing CO_2 through modern Carbon Capture and Storage (CCS) technologies is reported to be less costly in areas with depleted oil and gas wells [3]. DRI production is well established in the Gulf area with Iran as the biggest producer and production also in Saudi Arabia, Oman, UAE, Qatar, and Bahrain with a joint production of more than 33 Mton 2017 [6]. Increasing production would require international capital and building sites where international companies and different kinds of joint ventures may operate. The abovementioned countries all operate free zones for this purpose.

1-3- Outline of the paper

The hypothesis of this paper is that aging coke plants and a transition from the blast furnace route to electric furnace steelmaking will lead to drastic increased demand for DRI. This will make sourcing of suitable iron ore, finding suitable places for production and designing the DRI products a major issue. The effect of use in blast furnace and EAF operation is studied and the possible effects on how raw materials use and process investments may develop in the future. Finally the role of the Gulf area is discussed.

2- Economic basis for decisions

2-1- Basic assumptions

An increased demand for DRI is expected to increase the demand for seaborne pellets or pellets concentrate. Today a typical DRI-pellet feed has silicon content less than 2% whereas blast furnace pellets may have higher contents. An increased demand may make it necessary to accept higher levels even for DRI. For the blast furnace cases the main assumption is a fixed B2 slag basicity and other process parameters the same. For the EAF cases the main assumption is an MgO saturated slag and other process parameters the same. The calculations are performed with the RAWMATMIX® optimization system [9]. The blast furnaces and EAFs are assumed to be located in the EU whereas the DR plants are assumed to be located in the Gulf area.

2-2- Scenarios

Four different pellets are used as iron sources together with scrap: a low-Si DR-pellet (1), a high-Si DR pellet (2), a low-Si BF-pellet (1) and finally a high-Si BF-pellet (2). In a first study a BF operation with 100% of BF-pellet 2 is compared to a burden where 30% of the iron input is replaced by DRI made from the four pellet types. In a second study an EAF operation with 100% scrap is compared to burdening with 25%, 50%, 75% and 100% DRI of the four pellet types.

2-3- Input data

The analyses of the main raw materials are given in table 1. An excel sheet with complete data from this paper can be requested from the authors. The pellet types are chosen from pellets on the world market where DR-pellet 1 is a typical DR-pellet used in the Gulf area and in the USA. The analysis for DR-pellet 2 is taken from DR-pellets used to make commercially available Hot Briquetted Iron, HBI, from DRI. It is often used in amounts up to 30% in EAF production to abate tramp element content. BF-pellet 1 is a Swedish olivine pellets used in 100% pellet burdens in Sweden and BF-pellet 2 is a commercial blast furnace pellet used in Europe.

Table 1: Raw material chemical analysis for main elements and CO_2 value

Material Name	DR pellet 1	DR pellet 2	BF pellet 1	BF pellet 2	DRI 1	DRI 2	DRI 3	DRI 4	Scrap	Coke	Inject carb.
Fetot	68	67.4	66.7	65.1	92.76	90.23	90.15	87.16	-	-	-
Fe	-	-	-	-	87.19	84.82	84.74	81.93	98.0	0.40	0.39
C	-	-	-	-	2	2	2	2	0.40	89.0	92.43
Si	-	-	-	-	-	-	-	-	0.30	-	-
Mn*	0.015	-	0.04	0.03	-	-	-	-	0.80	0.01	0.004
P*	0.01	0.01	0.012	0.015	-	-	-	-	0.02	0.01	0.004
S*	0.003	-	0.001	0.008	-	-	-	-	0.03	0.57	0.72
FeO	0.5	0.4	0.5	-	7.16	6.97	6.96	6.73	-	-	-
SiO2	1.2	3.42	1.8	5.8	1.64	4.58	2.43	7.77	-	6.47	4.19
Al2O3	0.25	0.18	0.35	0.33	0.34	0.24	0.47	0.44	-	3.33	1.42
CaO	0.7	0.7	0.45	0.4	0.84	0.94	0.60	0.52	-	-	0.44
MgO	0.45	0.17	1.3	0.2	0.61	0.23	1.76	0.27	-	-	0.19
MnO	-	-	-	-	0.03	-	0.07	0.05	-	-	-
P2O5	-	-	-	-	0.03	0.03	0.04	0.05	-	-	-
TiO2	0.04	0.03	0.35	0.02	0.05	0.04	0.47	0.03	-	-	0.06
Na2O	0.025	0.08	0.04	0.05	0.03	0.11	0.05	0.07	-	0.05	0.033
K2O	0.015	0.04	0.02	0.12	0.02	0.05	0.03	0.16	-	0.14	0.12
CO_2eq/kg	0.137	0.137	0.137	0.137	0.82	0.81	0.81	0.812	0.002	0.22	0.22

*) Reported in this form for ores and carbon sources

The main process parameters for the blast furnace, the DR-shaft furnace and the electric arc furnace are given in table 2.

Table 2: Main production parameters

Parameter (Average)	Amount	Unit
Blast Furnace		
Blast volume	1140	Nm3/thm
Blast temperature	1010	°C
Blast moisture	9	g/Nm3
Oxygen enrichment	3	%
Slag Basicity	0.96	
Hot metal temperature	1480	°C
C% in hot metal	4.5	%
Si% in hot metal	0.55	%
Reduction Shaft Furnace		
Natural gas	10	GJ/t DRI
Electricity	100	kWh/t DRI
Metallization	94	%
Carbon content	2	%
Electric Arc Furnace		
Furnace burners	3000	kWh/Charge
Oxygen for slag foaming	1500	Nm3/Charge
Electrode consumption	4.38	kg/MWh
Tapping temperature	1600	°C
Tap weight	100	ton

Upstream CO2 emissions for some raw materials are given in table 3.

Table 3: CO_2 emission factor of raw material

Input source	Unit	Upstream CO2 kgCO2eq/unit	Comments
Limestone	kg	-	100%CaCO3
Burnt lime	kg	0.95	100%CaO
Burnt dolomite	kg	1.10	70%CaO,30%MgO
Magnesite bricks	kg	2.06	100%MgO
Coke	kg	0.22	
Inject coal	kg	0.22	
Electrode	kg	0.65	
Electricity(EU 25 gridmix)	kWh	0.54	
Electricity(Natural gas)	kWh	0.6	
Oxygen(EU25 gridmix el)	Nm3	0.26	ASU 0.48MWh/kNm3
Oxygen(Natural gas)	Nm3	0.29	ASU 0.48MWh/kNm3
Natural gas	Nm3	0.67	Process CO2 56.1 kgCO2eq/Nm3
LPG	GJ	8.0	Process CO2 factor 65.7 kgCO2 eq/GH

3- Results and Discussion

3-1- Blast furnace calculations

The calculations for use in the blast furnace show that the exchange of blast furnace pellets with DRI give a reduction of coke and PCI with 22% - 19% depending on the DRI. The quality of the coke and perhaps other circumstances determine if the entire reduction can be done on coke. Since the productivity in a blast furnace is dependent on the fuel rate this reduction also indicates a possible production increase in a single blast furnace of 20%. Results from the calculations are shown in table 4 and figures 1 and 2.

Table 4: Raw material use in base case with 100% BF-pellet 2 and calculation cases where 30% of the iron atoms have been charged as DRI made from the four pellet types.

		HM 100% BF-pellet 2	HM 70/30 DRI 1	HM 70/30 DRI 2	HM 70/30 DRI 3	HM 70/30 DRI 4
Coke	kg/t HM	333	238	242	240	249
PCI	kg/t HM	100	100	100	100	100
DRI	kg/t HM	0	304	313	313	324
BF pellet 2	kg/t HM	1354	925	923	922	921
Limestone	kg/t HM	93	56	69	61	86
Mn Briquettes	kg/t HM	65	65	65	65	65
BOF slag	kg/t HM	50	50	50	50	50
Slag amount	kg/t HM	214	170	184	179	203
Basicity	-	0.96	0.96	0.96	0.96	0.96
CO_2	kg/kg HM	1.623	1.480	1.473	1.498	1.548
CO_2 Reduction	kg/kg HM	-	143	150	125	75
CO_2 Reduction	%	-	8.8	9.2	7.7	4.6
Fuel rate	kg/t HM	433	338	342	340	349
Reductant saving	kg/tHM	-	-95	-90	-92	-84
Reductant saving	%	-	22	21	21	19

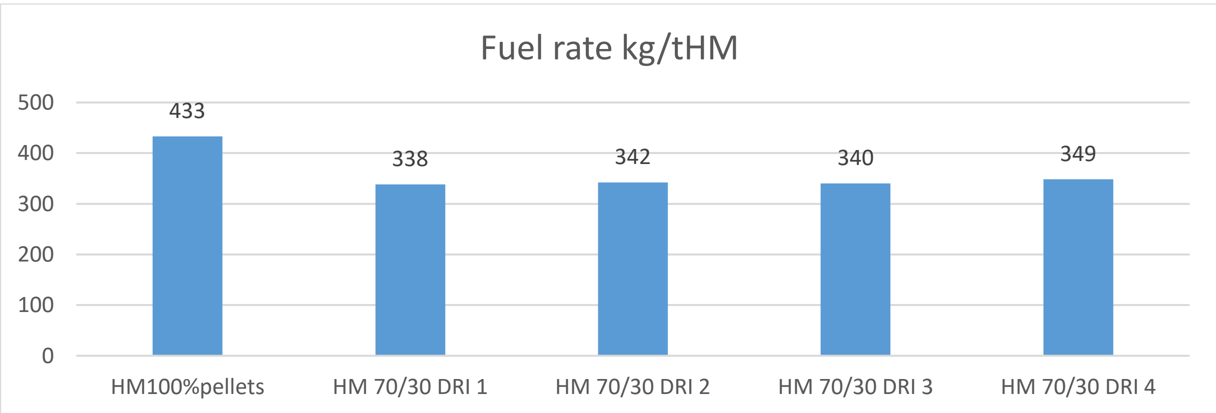

Figure 1: Fuel rate for reference case and cases with 30% DRI from different types of pellets.

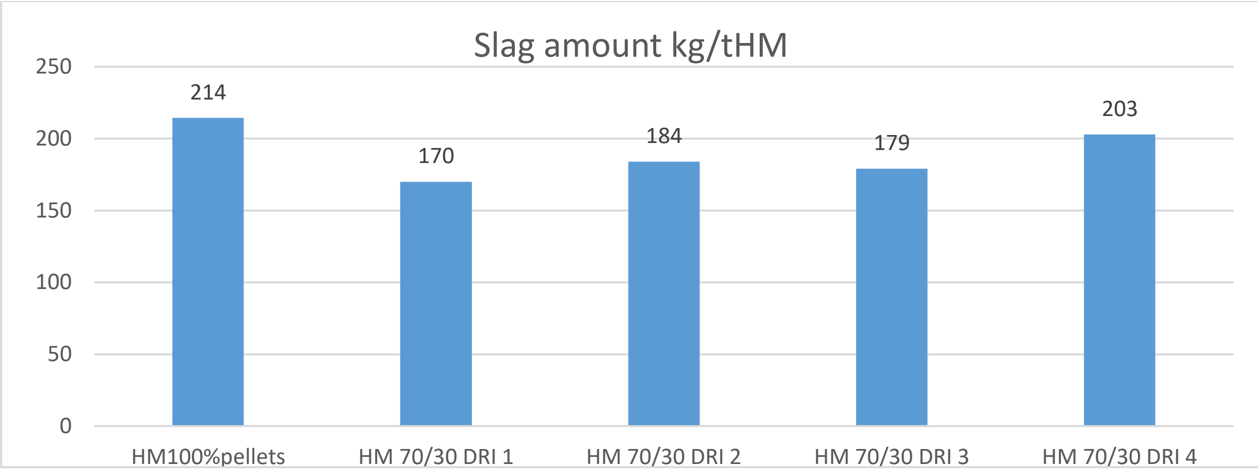

Figure 2: Slag amount for reference case and cases with 30% DRI from different types of pellets.

If the main purpose of using DRI in the blast furnace is to decrease coke consumption and increase productivity the choice of DRI is perhaps not critical. The slag amounts ranging from 170-214 kg/ton are all normal or even in the low range. In a case of reinvestment 20% of the coke and blast furnace capacity is no longer needed if the same hot metal production is to be achieved. If on the other hand as the main purpose a reduction in CO_2 emissions is desired the increased slag burden results in lower reduction of CO_2 emissions. Since DR2 has a higher CaO content than the other DRIs the requirement for limestone is lower which explains the lower CO_2 emission.

3-2- EAF calculations

Today it is a normal practice in the Gulf area to have a high amount of DRI in the burden and only use small amounts of scrap, mostly internal. In such cases the plant relies on DRI-pellets like DR-pellet 1 to get reasonably small slag amounts. Figure 3-5 show the consequences of having different types of DRI in the burden. Apart from a longer process time, higher energy use, higher slag former consumption, higher CO_2 emission, a higher slag amount results in higher iron losses since the FeO content in an EAF-slag often is around 20%.

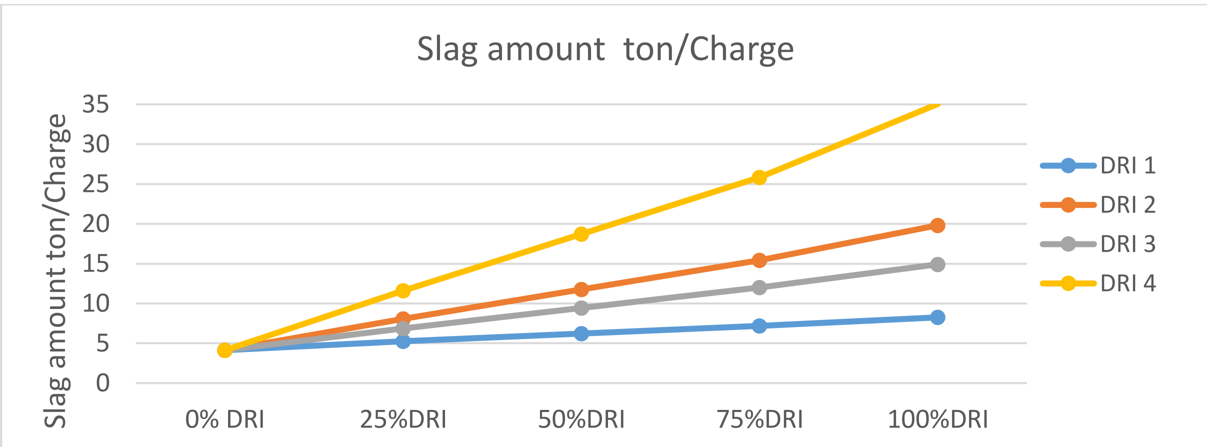

Figure 3: Slag amount in a 100 ton charge with different DRI-fractions in the burden.

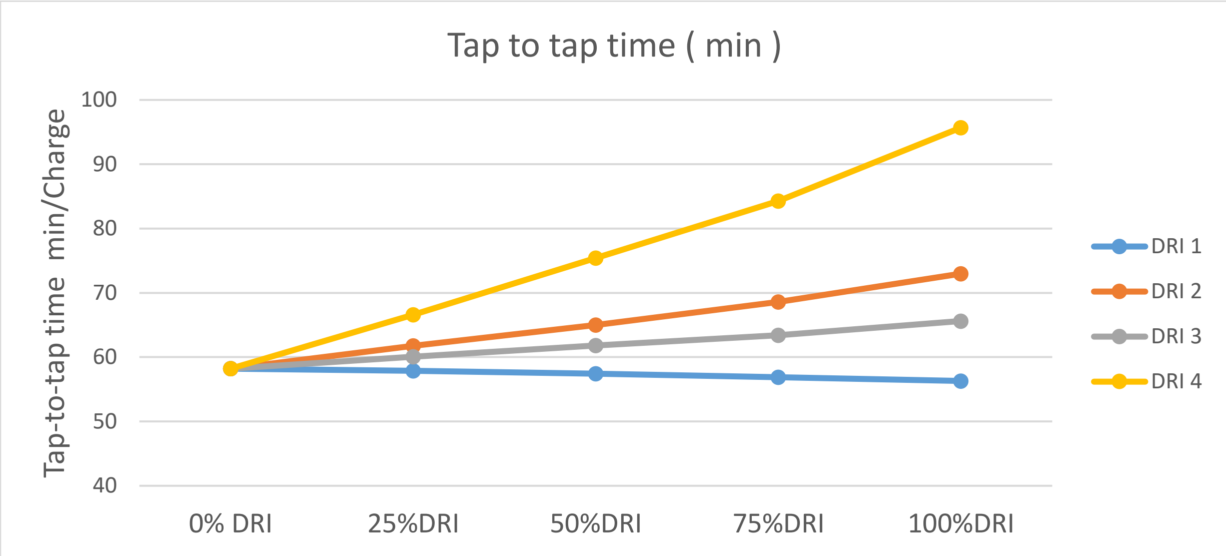

Figure 4: Tap to tap time in a 100 ton charge with different DRI-fractions in the burden.

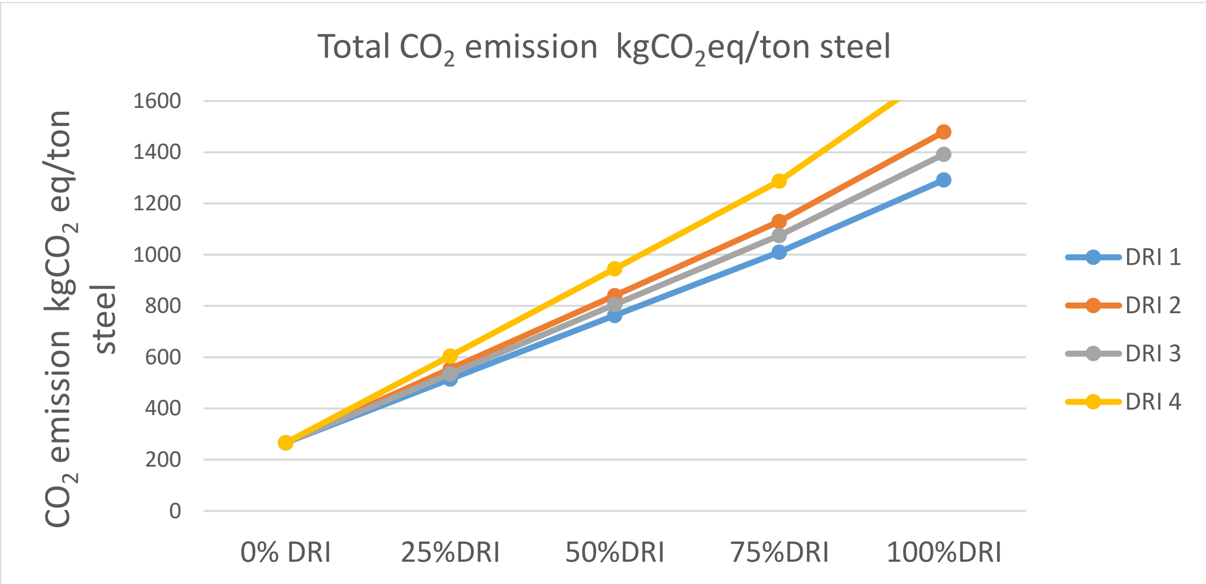

Figure 5: Slag amount in a 100 ton charge with different DRI-fractions in the burden.

For an EAF with a charge weight of 100 ton, a slag amount of 10 ton is considered high. Only DRI 1 achieves that for a burden with 100% DRI, while DRI 3 has an upper limit around 50%, DRI 2 around 37% and DRI 4 around 20%.

3-3- Discussion

The calculations in this paper are based on a base case with alterations aiming at studying the impact of raw materials with different silicon content. For the blast furnace the slag basicity has been kept constant and for the electric furnace the slag has been MgO saturated to assess a constant refractory wear other process parameters the same which of cause is a simplification. For example, the blast furnace calculations do not take the MgO into account when calculating the slag formers and an increased silicon input in the burden would increase the silicon content in the hot metal. It is however our view that it does not change the conclusions that can be drawn from the study.

The relevance of the study is the pressure on steel companies to change their impact together with an ageing infrastructure. In order to idle 20% of the worlds coke plants and blast furnaces through charging of 300 kg DRI/t HM in the blast furnace in order to produce the 1,247 Mton of Hot Metal produced today, an increased production of 374 Mton DRI is needed.

The open scrap market is relatively small compared to the apparent scrap use and changing behaviour of the net exporters to zero exporters or even net importers may change the market for scrap, metallics and ore completely. Scrap is a limited resource and increased DRI production may prove to be the only way to increase raw material supply for electric furnaces. The iron ore production is however not ready for this development. DRI-pellets are in short supply and DR-producers as well as DRI users will in the future have to accept higher silicon content in the pellets and in the DRI. As a consequence a mixed burden with scrap and DRI may in the future become the new normal. Applied on the 520 Mton of electrical steel and removing 100 Mton of DRI a rough estimation assuming 80% yield for DRI and 90% for scrap would result in 440 Mton steel from scrap and 489 Mton scrap needed for today’s production. A normal mix of 30% DRI in world electrical production would give 699 kton of steel from electrical furnaces, today not operating with DRI, with an additional DRI demand of 262 Mton.

The calculation example above indicates that there will be a shortage of scrap replacement and a growing market for DRI from the Gulf in the near future. How much depends on the pressure put on steel companies from customers, investors and governments. The countries in the Gulf have excellent prerequisites, with access to natural gas, a system with free zones or industrial parks that can attract investors and the necessary know how to produce DRI. Finally the main advantage may be the access to areas suitable for CCS which would make the DRI almost carbon neutral. A cooperation between several countries would here be preferable if possible to achieve.

4- Conclusions

In this paper we have discussed an alternative to reinvest in some of the ageing blast furnaces and coke plants as well as the need to find alternatives to scrap. DRI is a solution to these issues but a shortage of low silicon ore products may result in a new standard practice of scrap and DRI mixes making 100% scrap and 100% DRI charges less common. The paper also finds that the preconditions for DRI production in the Gulf are excellent. Especially the possibility of CCS and a “Gulf zero carbon DRI” product would be a much desired product on the market. With a DRI production of 33 Mton in 2017 a doubling or tripling of the production up to 100 Mton within the next ten years would be a reasonable goal.

Acknowledgements

The authors are grateful to Mr Magnus Tottie, LKAB, Mr Carl Petersohn, AGA, and Mr Anton Löf, RMG Consulting, for information about the ore and gas markets and fruitful discussions.

References

[1] Worldsteel, Steel’s contribution to a low carbon future and climate resilient societies, position paper, 2019

[2] P. Cavaliere, Clean Ironmaking and Steelmaking Processes - Efficient Technologies for Greenhouse Emissions Abatement, Springer Press 2019, ISBN 978-3-030-21208-7.

[3] S. Simbolotti, “CO_2 Capture and Storage”, IEA/ETSAP, Technology Brif E – 14, October 2010.

[4] Midrex, Direct from Midrex 2nd quarter 2010

[5] World steel association (2019) World steel in figures 2019

[6] World steel association (2018) STEEL STATISTICAL YEARBOOK 2018

[7] Magnus Tottie, LKAB, private communication 2019

[8] Carl Petersohn, AGA, private communication 2019

[9] RAWMATMIX® Systems Manual